Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Amendment of Parts 1, 2, 22, 24, 27, 90 and 95	)	WT Docket No. 10-4
of the Commission's Rules to Improve Wireless	)	
Coverage Through the Use of Signal Boosters	)	

COMMENTS OF SURECALL

As the Commission's *Second Order* correctly observes, the Consumer Signal Booster rules that the Commission adopted in 2013 "have achieved the Commission's goals of expanding Americans' access to well-designed boosters that do not harm wireless provider' networks."[1] Surecall actively worked with the Commission in developing those rules and subsequently redesigned all of its consumer-oriented boosters to comply with the Commission's requirements.

Five years later, Surecall is selling more than 30 thousand Consumer Signal Boosters a year, with annual growth in sales of approximately 30 percent.[2] Throughout this period, Surecall has not received any complaints of harmful interference resulting from its booster

[1] Amendment of Parts 1, 2, 22, 24, 27, 90 and 95 of the Commission's Rules to Improve Wireless Coverage Through the Use of Signal Boosters, Second Report and Order and Second Further Notice of Proposed Rulemaking, WT Docket No. 10-4, FCC 18-35 (March 23, 2018) ("*Order*" or "*Second Further Notice*").

[2] Based in Silicon Valley, Surecall is an innovation leader in cellular amplifier technology that dramatically improves cellular communication for businesses, homes and in mobile settings. Surecall has been repeatedly recognized for its corporate growth, engineering innovation and product performance in various awards. During the past year, these awards have included: 2017 Top-50 Fastest-Growing Private Companies in the East Bay; 2017 Top-100 Fastest-Growing Private Companies in the Bay Area; 2017 CE Pro BEST Award; 2017 Commercial Integrator BEST Award; 2017 TMC Communications Solutions Product of the Year; 2017 CEDIA Best of Show. Additionally, Surecall earned a place on the 2017 Inc. 5000 List of Fastest Growing Private Companies for the second consecutive year.

products, clearly demonstrating that the Network Protection Standard ("NPS") was more than adequate to ensure the protection of wireless networks.

As the Commission's *Second Order* also acknowledges, the rules that were adopted in 2013 "were conservatively designed."[3] Surecall asserted at the time – and continues to believe – that the 2013 rules were more stringent than necessary to protect wireless networks adequately. Further, the Commission's imposition of a personal use restriction on Consumer Signal Boosters directly undercut the Commission's express goal of ensuring that reliable and cost-effective boosters would be available to "benefit consumers by improving wireless coverage in office buildings where they work, in health care facilities, where doctors and health care providers need reliable communications, and on educational campuses where students want access to the latest wireless applications."[4]

The personal use restriction effectively prohibited nearly all of these highly beneficial applications, along with other important uses, such as in support of public safety.[5] The *Second Further Notice* now acknowledges this, explaining the personal use restriction denies "a crucial tool for improving wireless service access to a range of entities—including businesses of all sizes, public safety entities (using commercial spectrum), educational institutions, and others."[6]

All end users of wireless products, be they in their homes, at work, in schools, stores or on the road, deserve access to low cost and reliable booster devices that can help ensure their

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[3] *Id.* at 9.

[4] Amendment of Parts 1, 2, 22, 24, 27, 90 and 95 of the Commission's Rules to Improve Wireless Coverage Through the Use of Signal Boosters, Report and Order, WT Docket No. 10-4, FCC 13-21,¶ 7 (Feb. 20, 2013) ("*2013 Order*").

[5] *See id.*, ¶ 8 (observing that "[f]irst responders, including emergency medical personnel, also use signal boosters to improve communications during disasters and other emergencies").

[6] *Second Further Notice*, ¶ 36.

uninterrupted access to broadband communications services. This public interest need cannot be satisfied by provider-specific signal boosters, which are often much more expensive (particularly when multiple devices are purchased to address multiple carriers) and can lock consumers into relationships with a single carrier, even when other carriers may provide better service for less money.

The important role of wideband Consumer Signal Boosters will continue to increase as broadband wireless services employ increasingly higher spectrum bands using 5G technologies. As the Commission acknowledged in its *Spectrum Frontiers Order*, the use of millimeter wave ("mmW") technologies for broadband data transmission in spectrum bands above 24 GHz will be characterized by "short transmission paths and high propagation losses,"[7] necessitating the need for signal boosters to increase the reach of mmW small cell networks. Wireless broadband coverage of indoor locations (where most smart phones are used) will also be extremely difficult using mmW spectrum bands because mmW signals "are more severely attenuated due to obstacles such as foliage and walls."[8]

Surecall therefore strongly supports the Commission's proposal to: (1) eliminate the personal use restriction for wideband Consumer Signal Boosters, (2) expand the frequencies available for wideband boosters to all spectrum bands that are available now and in the future by commercial mobile radio service ("CMRS") providers, and (3) facilitate compliance with the customer notification process for signal boosters embedded in vehicles.

[7] Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, GN Docket No. 14-177, Report and Order and Further Notice of Proposed Rulemaking, FCC 16-89, ¶ 6 (July 14, 2016) ("*Spectrum Frontiers Order*"); *see also id.*, ¶ 271 (observing that "[t]he lower range and shorter propagation distances at these frequencies will substantially constrain 5G deployment").

[8] *See id.*, ¶ 276.

I. NO TECHNICAL OR PUBLIC POLICY REASON EXISTS TO PROHIBIT BUSINESSES AND WORKING CONSUMERS FROM USING WIDEBAND CONSUMER SIGNAL BOOSTERS TO ENSURE WIRELESS CONNECTIVITY

The Commission's *Second Further Notice* identifies two potential issues with respect to removing the personal use restriction on wideband Consumer Signal Boosters. First, the *Second Further Notice* briefly inquiries whether any technical impediments exist to the operation of wideband Consumer Signal Boosters for non-personal purposes. Second, the *Second Further Notice* seeks comment on how best to address the absence of a direct subscriber relationship between the owner/operators of wideband Consumer Signal Boosters and the various wireless carriers. As explained below, neither of these issues justify the retention of the personal use restriction for wideband Consumer Signal Boosters, particularly when balanced against the important benefits to enterprises and their customers that wideband boosters can provide.

A. No Technical Basis Exists for Continuing the Personal Use Restriction for Wideband Consumer Signal Boosters

The *Second Further Notice* addresses in a single sentence the claim of one booster manufacturer – Nextivity – that "widespread use of Wideband Consumer Signal Boosters in the absence of the personal use restriction raises myriad potential performance and interference issues that need to be evaluated before such a restriction is lifted for this category of signal boosters."[9] This cursory treatment is appropriate. Wideband Consumer Signal Boosters are already being used simultaneously by subscribers of multiple carriers without resulting in harmful interference to wireless networks or to the communications of individual subscribers.

For example, as the Commission anticipated in its *2013 Order*, wideband signal boosters purchased for personal use are already being used in residential environments by roommates,

[9] *Second Further Notice*, ¶ 41 (*citing* Nextivity *Ex Parte* at 5-7).

housemates and family members that subscriber to different wireless carriers.[10] The fact that such use has not resulted in harmful interference to wireless communications should be sufficient to dispel any claim that the use of wideband signal boosters by subscribers of multiple carriers raises potential performance or interference issues.

With respect to Nextivity's specific claim, it is focused on an extremely unlikely condition in which the uplink (user to network) transmissions of two mobile devices using different frequency bands through the same booster could create an intermodulation signal within the booster that could interfere with the downlink (network to user) transmission to a third mobile device operating with the same booster using a third frequency band.[11] As explained in the attached technical analysis, the purported intermodulation event could occur only in very rare circumstances in which the following six conditions occur simultaneously:

1. three different mobile devices must each be using one of three specific frequency bands within the same booster and
2. two of the mobile devices must both be transmitting in the uplink direction at their full (+23 dBm) power level and
3. the two mobile devices must be (and remain) equidistant from the booster,[12] and
4. the booster must be operating at its full uplink power level, and
5. the third mobile device must be receiving a downlink signal also in a specific frequency band and
6. the downlink signal from the network to the booster's external antenna must be -88 dBm or weaker.

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[10] *See Second Further Notice*, ¶ 48, n.105 (acknowledging that "two housemates or family members with different wireless providers intending to use a single Wideband Consumer Signal Booster would each seek consent from their wireless provider").

[11] See Nextivity *Ex Parte* Letter, March 22, 2017, Attachment 1 at 4.

[12] Or the mobile devices can be at different distances from the booster, but with their respective uplink power levels adjusted so the input power at the booster from the two devices is identical.

Employing very reasonable assumptions, Surecall has calculated that the chances of this occurring are on the order of 0.0000945 percent or 1 out of every 1,058,201 call combinations using a wideband Consumer Signal Booster.

Further, even if this condition were to occur, the mobile device that is receiving the downlink signal with an intermodulation component would immediately detect the increase in bit error rate and would request and secure approval from its wireless network to switch to another frequency. Therefore, any interference resulting from such an intermodulation condition would be extremely brief and likely unnoticeable to the end user. Therefore, no legitimate technical impediment exists to the immediate removal of the personal use restriction for wideband Consumer Signal Boosters.

B. No Legal Basis Exists for Continuing the Personal Use Restriction for Wideband Signal Boosters

The *Second Further Notice* also seeks comment on that fact that the owner/operator of a wideband signal booster may have a subscriber relationship with only one of the wireless carriers that the booster's frequency range can cover.[13] As a result, third party mobile devices may use the booster to connect with their own wireless networks without any relationship existing between those other wireless network operators and the owner/operator of the booster.

The *Second Further Notice* proposes to address this issue be requiring the owner/operator of a wideband Consumer Signal Booster that is placed in an enterprise environment to register the booster with every wireless carrier that serves that location.[14] Surecall believes that, as long as the registration process is not lengthy or otherwise burdensome, the Commission's proposal

[13] *Second Further Notice,* ¶¶ 43-44.

[14] *See id.,* ¶ 47.

would be an appropriate approach to enable the elimination of the personal use restriction for wideband Consumer Signal Boosters.[15] Rather than have each carrier maintain its own database, however, it would seem more appropriate to have an organization representing the wireless carriers, such as CTIA, administer the database, just as CTIA already does with respect to the Stolen Phone Checker database, the Short Code Registry, and the National Emergency Address Database ("NEAD").[16]

Requiring signal booster owner/operators to register their devices in a database that is available to all of the wireless carriers would be the logical outgrowth of the Commission's 2013 decision approving the personal use of Consumer Signal Boosters. Specifically, the *2013 Order* openly acknowledged that Consumer Signal Boosters that are registered for personal use with one wireless carrier will, on occasion, be used by individuals that subscribe to other wireless operators. First, the *2013 Order* recognized that owners of Consumer Signal Boosters may have friends and neighbors who may visit their home and may make wireless calls that will be retransmitted through the network of the acquaintance's serving carrier by the individual's signal booster. The *2013 Order* authorized this transient use by describing it as incidental and *de minimis*.[17] The *2013 Order* then acknowledged that this third party use will be "routine" in some cases.[18] For example, in some residential situations – such as apartment buildings,

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[15] *See* https://www.ctia.org/about-ctia/programs (*last visited* May 14, 2018).

[16] *See* http://www.911nead.org/ (*last visited* May 14, 2018).

[17] *See 2013 Order*, ¶ 48.

[18] *See id*.

condominiums, roommate situations, or in dorms or group homes – numerous individuals use the same Consumer Signal Booster to support their personal wireless needs.[19]

Rather than attempt to prohibit such routine third party use, the *2013 Order* more appropriately instructed that, "[i]f a third party intends to use a Consumer Signal Booster on a regular, sustained basis, the third party must seek its provider's consent to do so."[20] Further, "if a consumer purchases a Consumer Signal Booster for use in a location where subscribers of multiple serving providers will access the device regularly, each such subscriber must register the device with their provider."[21]

Therefore, the only change that is being proposed in the *Second Further Notice* is to have the owner/operator of the wideband booster register the device with every wireless carrier, rather than have the various end users separately register the booster with their own wireless carriers. This new approach seems far more efficient and – of equal importance – more likely to secure consumer compliance in the registration process. After all, if an individual living in an apartment building suddenly notices that his or her wireless signal coverage has improved dramatically, they will likely conclude that their carrier has made improvements to its network, rather than realizing that their neighbor (possibly living on another floor) has purchased a Consumer Signal Booster. Therefore, the owner of the wideband booster, rather than its

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[19] *See id.*, ¶ 48, n.105 (acknowledging that "two housemates or family members with different wireless providers intending to use a single Wideband Consumer Signal Booster would each seek consent from their wireless provider"); *see also id.*, ¶ 104 (explain that "if a consumer purchases a Consumer Signal Booster for use in a location where subscribers of multiple serving providers will access the device regularly, each such subscriber must register the device with their provider").

[20] *Id.*, ¶ 48.

[21] *See id.*, ¶ 104.

various (potentially unknowing) users would be the most appropriate person to complete the registration process.

II. SIGNAL BOOSTERS SHOULD BE PERMITTED TO OPERATE ON ALL CMRS FREQUENCIES

The *Second Further Notice* request comment on whether to modify the Commission's rules to expand the range of frequency bands that are available for the operation of Consumer Signal Boosters.[22] Rather than individually identify the frequency bands that are available to Consumer Signal Boosters, Surecall urges the Commission to create a blanket rule that Consumer Signal Boosters are authorized to operate using any frequency bands that are authorized for use by CMRS providers. The use of such a blanket approach will avoid the administratively burdensome process of requiring a modification to the Commission's rules for signal boosters each time additional spectrum is made available for CMRS. Such an approach will also fulfill the reasonable expectations of consumers, which seek to purchase signal boosters that are able to operate on all of the same frequencies that their smartphones and other mobile devices are able to employ.

The *Second Further Notice* observes that, in identifying additional frequency bands that could be made available for the operation of Consumer Signal Boosters, consideration may be necessary with respect to whether the existing technical rules for Consumer Signal Boosters will need adjustment to address the additional frequency bands, such as developing specific rules governing noise and gain limits for booster operations in each band.[23]

22 *See Second Further Notice*, ¶ 18.

23 *See id.* ¶ 23.

Surecall does not believe that any significant adjustments are necessary because the existing technical rules were originally drafted with the addition of new frequency bands already taken into consideration. Specifically, the existing noise and gain limits for Consumer Signal Boosters – which were the product of an industry consensus position[24] – already include "the mid-band frequency of the supported spectrum bands in MHz"[25] as one of the variables in the calculation of the allowable noise limit (−102.5 dBm/MHz + 20 Log10 (Frequency)) and the allowable maximum gain (6.5 dB + 20 Log10 (Frequency)) for wideband signal boosters. Thus, no change in the rules will be needed to made additional CMRS frequency bands available for use by Consumer Signal Boosters.

Some modification, however, will be needed to Section 20.21(e)(2) of the Commission's rules addressing the "certification requirements" for signal boosters. The existing Section 20.21(e)(2) separately identifies each of the CMRS frequency bands that are currently available for signal boosters and explains that, for all of them, signal boosters must comply with the band-specific rules for each frequency band unless the booster-specific rules in Section 20.21 are more stringent.[26] In order to simplify this provision, the certification section should be revised to make a blanket reference to all frequency bands available for CMRS operations. The certification section should continue to instruct, however, that signal boosters must comply with the band-specific rules for each band that is available for CMRS unless the booster-specific rules in Section 20.21 are more stringent.

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[24] Letter from Nextivity, T-Mobile, V-COMM, Verizon Wireless, and Wilson to Marlene H. Dortch, Secretary, Federal Communications Commission, WT Docket No. 10-4 (June 8, 2012).

[25] *See* 47 CFR § 20.21(e)(8)(i)(A)(2)(i), (e)(8)(i)(C)(2)(ii), (e)(9)(i)(A)(2)(i), (e)(9)(i)(C)(2)(ii).

[26] *See* 47 C.F.R.§ 20.21(e)(2)(ii).

III. THE COMMISSION SHOULD MODIFY ITS CONSUMER NOTIFICATION REQUIREMENTS TO FACILITATE THE USE OF EMBEDDED CONSUMER SIGNAL BOOSTERS

When the very first mobile phones were developed, their primary market opportunity was providing voice telephony in cars. Although the wireless industry has expanded exponentially since then, it remains the case that a lot of wireless calls are made by individuals in their vehicles. Unfortunately, the quality and reliability of those wireless calls and the frequency of "dropped" calls while driving is still very dependent on the conditions surrounding the various roads that are traveled on and the proximity to the nearest cell tower. Therefore, the installation by automobile manufacturers of embedded signal boosters in new cars would assist greatly in resolving mobile connectivity concerns. Embedded signal boosters have tremendous advantages over "out of the box devices," including simplicity for consumers and assurances for the wireless carriers that the embedded boosters will be installed appropriately and will not be subject to tampering following installation.

In order to facilitate the use of embedded signal boosters in vehicles, the Commission should modify its rules to permit automobile manufactures to provide the various notifications and instructions that must be distributed with Consumer Signal Boosters either as a part of the automobile user manual, or accompanying the manual in an easy to review format. Such an approach would help to ensure that purchasers of new automobiles review the booster-related materials, either as a part of the purchase of their vehicle or thereafter when they seek to use the embedded booster. Further, consumers routinely retain the manuals and other paperwork provided during the sale of a new car (usually keeping them in the "glove compartment"). Thus, the materials will remain available for future reference.

IV. CONCLUSION

As the *Second Further Notice* acknowledges, NPS-compliant Consumer Signal Boosters serve an important and expanding role in helping to close the digital divide in mobile broadband communications. The Commission should continue to facilitate this effort by eliminating the personal use restriction for wideband Consumer Signal Boosters in order to ensure that all consumers can enjoy reliable mobile broadband connectivity, including working consumers in their places of business, where they shop, where they receive important services and where they attend school. The Commission should also expand the range of frequencies used by Consumer Signal Boosters to all bands that are available for CMRS. Finally, the Commission should modify its customer notification requirements in order to facilitate the installation of embedded signal boosters in new cars by automobile manufacturers.

Respectfully submitted,

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Intermodulation in Wideband Signal Boosters

May 18, 2018

The Federal Communications Commission ("Commission") has adopted a Notice of Proposed Rulemaking ("NPRM") that considers whether to remove the "personal use" restriction on wideband consumer signal boosters. The NPRM seeks comment on claims by one party that intermodulation in the uplink path of a wideband signal booster could cause adverse effects in the downlink path of the same booster. This paper demonstrates that such an intermodulation condition would almost never occur and, if it does, any potential negative impact would be negligible and would be limited to the single end user device receiving the intermodulation condition, and not to the wireless network.

Background on intermodulation issue

Intermodulation distortion ("IMD") can occur as a result of the combination of signals containing two or more different frequencies caused by nonlinearities in a system. All amplifier systems exhibit this behavior to a certain respect because there is no practical way to design a perfectly linear system. The intermodulation between two frequency components will form additional components at frequencies that are based on the two main components that can be mathematically computed. The largest IMD products are the ones that are generated closest to the source frequencies and are called the third order IM components (IMD 3). They are calculated as follows:

F_1 = source frequency component 1

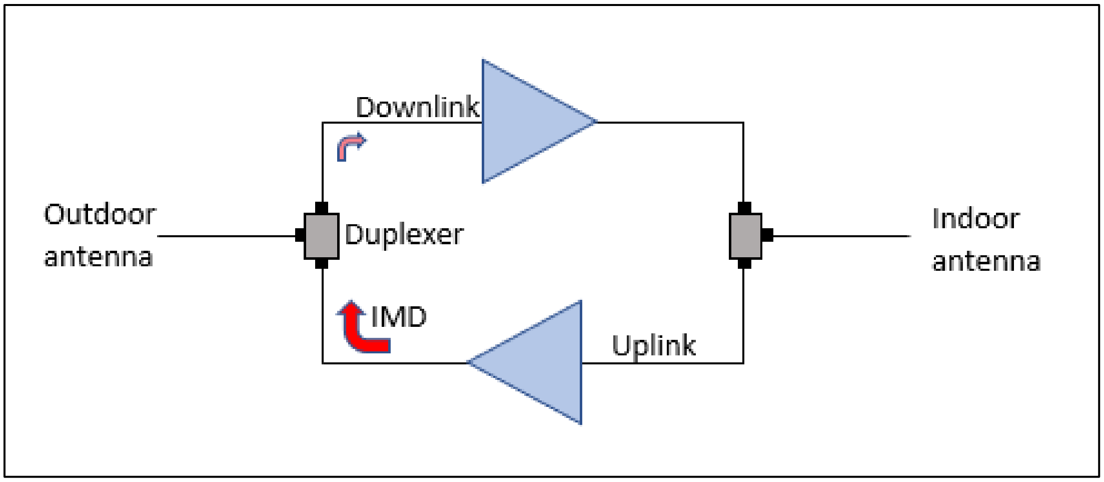
F_2 = source frequency component 2

IMD 3 component 1 = $2 \times F_1 - F_2$

IMD 3 component 2 = $2 \times F_2 - F_1$

In the cellular booster design, the IMD products generated in the uplink direction are carefully tested such that these signals will be low enough to not affect the mobile phone operation. This is mandated by Section 20.21(e)(8)(i)(F) of the Commission's rules, which is one of the significant changes made by the Commission when it incorporated the Network Protection Standard into its technical requirements for Consumer Signal Boosters.

One party, however, has claimed that the uplink IMD products in a wideband Consumer Signal Booster can be amplified in the downlink path to the point where they will affect the performance of the signal received by a mobile phone that is operating with the booster. Due to the nature of the wideband booster design, it is possible for these low level IMD products to enter the downlink path of the amplifier. The diagram below illustrates how these signals enter into the downlink path, crossing through the transmit and receive ports of the duplexer component. The IMD products are significantly attenuated through this path, yet some leakage can occur, which would be transmitted through the downlink RF path to the booster's indoor (server side) antenna port.



It has been presented that this can happen in the PCS band when two mobile phones are on specific frequencies that can generate an in-band IMD product that would be received within the downlink PCS band. The resulting intermodulation signal, however, will be low enough such that it generally will not have a detrimental impact to mobile devices operating inside the building. The question raised is whether this can affect the downlink signal received by a mobile phone in practical, real life conditions.

Examining how often this can happen

There are many factors in considering the likelihood or probability of an IMD product being generated in the downlink path and whether it can impact the performance of a mobile device using the same booster. All of these factors must be considered to determine the probability that this intermodulation issue will cause an issue with the downlink signal received by a mobile device.

1) Small subset of frequency pairs show up in the downlink

Since the IMD products can be calculated from the formulas above, it can easily be determined how often these frequencies fall into the downlink path of the same band. The Figure below shows the results in the PCS band using all combinations of uplink frequency pairs and indicates that this condition has the possibility to occur only **22.6%** of the time. The vast majority of the time, or **77.4%** of the time, the frequency pair assignments in PCS spectrum result in an intermodulation frequency assignment that is outside the PCS band, and not received in the downlink spectrum at all.

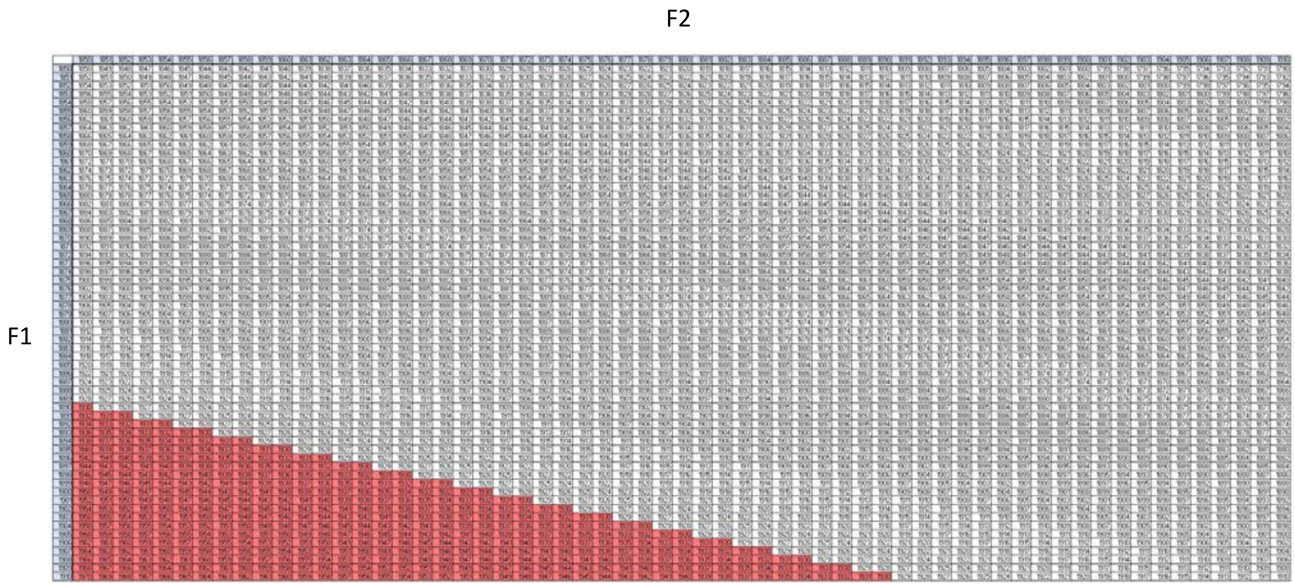


Figure 1 – PCS Frequency pairs shown in red when IMD products are received within the PCS band

When considering all of the frequency bands permitted for consumer signal boosters for a 5-band consumer signal booster, the results are as follows:

Band 2 (PCS)	22.6%
Band 5 (Cellular 850MHz)	0%
Band 12 (AT&T 700MHz)	0%
Band 13 (Verizon 700MHz)	0%
Band 4 (AWS)	0%

As shown above, four out of the five spectrum bands permitted for consumer signal boosters have a **0%** probability of the intermodulation component being received in band. The only band that has a theoretical possibility is the PCS band with a 22.6% chance of occurring mathematically. The two mobile phones operating in the PCS band that would produce the IMD product in the downlink path would need to be operating on one of the frequency pairs identified in red in the Figure above. Due to the possible frequency combinations in the PCS band, there is only a one percent chance that one of the two mobile phones that generated this IMD product will also be receiving this IMD product on its assigned downlink PCS frequency. Therefore, if the IMD product is received by any mobile device within the building, the vast majority of the time (*i.e.* 99% of the time) it would require a third mobile device that is receiving the downlink signals using the same booster at the same time as well.

2) Two signals need to be at the same input power level to the booster and operate at a level that would result in the booster operating at its maximum output power for this condition to occur

In order for this IMD product condition to occur, there must be two mobile signals from wireless devices received at the booster on the uplink path that are operating at the same power level, and the power level of both devices would need to be at a level that results in the booster operating at its maximum output power. If either signal has a lower power level, the resulting IMD product magnitude would be significantly reduced to a much lower level and would not have any noticeable effect on downlink signals received by mobile devices. In real life applications, this would be extremely unlikely due to the propagation loss over-the-air before the mobile phone uplink signal reaches the booster's inside antenna. Both phones would have to be operating at full +23dBm output power and would have to be located equidistant from the booster's antenna and close enough to the booster for it to be able to reach its maximum uplink output power level. Alternatively, the power could be lower on one handset if that handset is located an exact distance closer to the booster such that the received signal is the same for both mobile devices. This condition would generally not occur often as exact placement of the mobiles would be required to achieve this and, if occurring, and would likely occur only briefly given that mobile phones are usually in motion.

In addition, the signal strength of the two equal power wireless devices must be high enough and close enough to the booster such that they cause the amplifier to be operating at the maximum uplink power level. The IMD is caused by the non-linearities of the amplification path, and when the amplifiers are operating below their full power, they will have much more linearity and the resulting IMD will be significantly attenuated to the point that it is non-existent. Thus the booster must be at full uplink output power for the IMD component to be included in the downlink signal.

3) There are not that many active users simultaneously serviced by a single consumer signal booster

For a wideband consumer signal booster to generate the IMD product, Nextivity stated that the uplink signal must be received by the booster at a power level of at least a -55dBm. It was also pointed out that by using a standard propagation model, this would mean that a handset operating at an uplink output power of +23dBm could be as far away as 25 meters (distance for 78dB of path loss). However, the propagation model that was used to support this conclusion includes only a single wall obstruction and does not account for normal indoor propagation losses in its attenuation calculations. Therefore, it is not appropriate to model the indoor attenuation in such enterprise environments as office and other commercial buildings.

The standard indoor propagation model for office and commercial buildings is the **ITU indoor propagation model**, which provides the propagation path loss inside a building, room, or a closed area delimited by walls of any form[1]. With this formula, the maximum distance for the two devices to be located from the uplink receive antenna of the booster and potentially create an IMD product in the PCS band is **9.5 meters**. In addition, the propagation losses would be even greater if other typical losses were considered such as device antenna polarization losses and head and body losses resulting from the end user, which are both approximately 8 dB for the PCS band. These factors would further reduce the maximum distance considerably for the devices to be located away from the booster and still produce an IMD condition. Thus, the maximum distance calculated (9.5m) is very conservative for this analysis, and in many cases would be much smaller.

For a single booster, the 9.5 meter coverage area from the booster would normally accommodate no more than ten end users. Out of those ten users, we assume a typical condition of three active users using their mobile phones simultaneously. The possibility that all three of these wireless devices would be on the three specific PCS frequencies that would result in an IMD condition would be an extremely rare occurrence. There are five available frequency bands of operation, so it would be very rare for all of the three devices to be assigned to the PCS band, and even more rare for two of the devices to be on the PCS frequency pair that would generate the IMD product in the downlink, and even more rare for the third phone to be using the sole PCS frequency containing the IMD product.

4) The IMD could have an effect on the downlink only if the outside signal is weaker than -88dBm

In the remote event that the above conditions are met and, as a result, the IMD component is present in the downlink path that a mobile phone is using, it will still have no consequence unless the outside signal that is received by the booster from the network is well below -88dBm as received at the booster donor port.[1] However, office buildings that occupy large groups of people are generally located in areas that are more populous. In a large percentage of office buildings, the need for a consumer booster is to correct for the poor signal penetration into the building, not to correct for a weak outdoor signal. For booster installations in larger buildings, it is also very common (if not required) to use directional high-gain external antennas to ensure the downlink signal from the network is being captured properly. Because of this, it is rare for the downlink signal strength captured to be as weak as -88dBm in a non-residential environment and thus the desired signal would be significantly stronger than the very low level intermodulation signal occurring in the downlink path and will not impact service.

5) Aa received power level of -88dBm at the booster's external antenna would result in an unusable in-building received signal without the booster

In the case of a low outdoor signal level of -88 dBm/10MHz and taking into account the industry standard building penetration loss of 12 to 20 dB for standard to commercial buildings, the desired received signal level inside the building would be equivalent to -100dBm to -108dBm/10MHz at the mobile devices. Thus, in these cases, there would be no service available at all inside the building absent the availability of a signal booster to raise the desired signal level inside the building to a usable level. Therefore, the booster can only improve and enhance the wireless service in this situation. For example, even in the impossible case that the IMD occurs 100% of the time and it impacted 100% of the mobiles inside the building, it still should not be construed as harmful interference because the mobile devices inside the building would not have been able to receive the wireless service at all without the assistance of the signal booster.

6) With IMD present in the downlink, a mobile phone would choose a different band or channel

In the event this IMD product could occur in the PCS frequency block that a mobile phone is using and it is significant enough for the phone to experience a degradation in bit-error rate, the mobile device would respond to the interference by switching to a different frequency band or channel as instructed by the wireless system that monitors such performance on channels (*i.e.*, with system schedulers in 4G LTE systems). Since these are wideband boosters, there are several other bands and frequency blocks to operate on, and so this condition would likely be short lived even if it were to occur. If the mobile phone was not able to switch frequencies, then it could change its modulation type to one that does not need as much of a signal-to-noise ratio, such as 16QAM, QPSK, WCDMA or CDMA and operate at a slightly lower data rate.

Also, as mentioned previously, the IMD condition could only occur if the downlink signal that is received from the network is very weak, in which case it is likely that one of the other available frequency bands would have a stronger downlink signal. In this case, it can be anticipated that the mobile phone would

[1] This level was referenced in the Nextivity Analysis as the downlink input level to the wideband consumer booster when this reverse IM issue can occur.

never be on the band experiencing a very weak signal because there would be a band with a stronger and better quality signal that the wireless network would have been assigned it to use.

Calculating the probability of the IMD issue on downlink

Certain assumptions must be made in order to calculate the probability of an IMD product occurring and being received in the downlink band for mobile devices in the building. For simplicity, below we use a 5MHz LTE signal for the uplink from the mobile devices. In addition, we use a maximum of three active users within 9.5 meters using the booster (as discussed above).

For the IMD product to be an issue, all three mobile devices would have to be on the exact three frequencies that would create this IMD condition (F1, F2, and the IMD frequency). Since we are using 5MHz bandwidth signals, we can determine how many frequency blocks could be assigned to the mobile devices within the building, which are shown in the table below.

Cellular Band	# Blocks
Band 2 (PCS)[1]	12
Band 5 (Cellular 850MHz)	4
Band 12 (AT&T 700MHz)	3
Band 13 (Verizon 700MHz)	2
Band 4 (AWS)	9
Total	**30**

Thus there are a total of 30 blocks of 5MHz that a mobile device could potentially be assigned by the network and actively used through a consumer signal booster (this conservatively excludes other new CMRS bands not presently permitted for consumer boosters). When three wireless devices are in use, the probability that all three would be on the PCS band is 6.4%[2]. In addition, the probability that two of these devices would be on the frequencies that will cause the IMD product is approximately 5.1%[3]. Further, the third device would need to be on the frequency channel that contains the IMD product, the probability of which is 1 out of 12, or 8.3%. Thus, **the probability of three phones being on the necessary frequency blocks for this condition to occur is very remote and equal to 6.4% × 5.1% × 8.3%, or 0.027%**. The probability is likely even less because, if the outside received signal from the network is -88dBm or lower, there is a strong possibility that the wireless network would have instructed the mobile phones to operate on different bands with better signals.

Even when all of the above conditions are met, the IMD product will still not occur unless the two frequencies are input into the booster's receive antenna at equal levels, and these levels must be strong enough to prompt the booster uplink amplifier to increase to its full output power. To receive the signals from two mobile devices at the same power level, they must be transmitting at the same power level (assuming the propagation loss within 9.5 meters is within 6dB and thus still causes an IMD product). The maximum power level for LTE is +23dBm, yet this power is controlled by the base station and can be as low as -40dBm in 1dB steps. Assuming that handsets are not usually operating at low power levels indoors for LTE, we considered a range of +23dBm to -20dBm as the range of possibilities for mobile device output power. In addition, we assumed the power for each frequency has to be within 6dB to create enough of an IMD product to be an issue. The probability of two handsets being within 6dB of each other is 6/43, or 14.0%. In addition, these power levels have to be high enough to force the booster uplink to operate at full power. For the mobile devices that are 9.5 meters from the booster, they will have to operate at full power to meet these conditions; and for mobile devices that are closer to the booster, they will still require at least approximately +10dBm of output power from both handsets. This results in approximately 25 percent of the devices meeting the power level requirement. Combining these factors, **the probability that the signals will be strong enough and are received at the booster at the same level is 3.5%** (14.0% x 25%).

Finally, we need to add the condition that the outside received signal must be -88dBm or weaker for the IMD product to have an adverse effect on the downlink signal. Based on our lengthy experience in the booster industry, we conservatively estimate that **the probability of the downlink signal strength being at -88dBm or lower at the rooftop of the building is less than 10% of the time**.

To determine the resultant probability of the IMD actually potentially impacting the mobile device, we need all three of the above conditions to be met. **Thus the total probability of an IMD issue affecting a mobile device is 0.027% x 3.5% x 10%, or 0.0000945%. This is equivalent to 1 out of 1,058,201**.

Obviously, this does not rise to a level that can be considered harmful interference, and even in the unlikely event it could mathematically occur, it still would be at a level that is too low to have a significant impact to the performance level of the devices operating within the building.

Furthermore, when this condition occurs, it is very likely that the mobile phone experiencing the IMD in the downlink will change bands, as a result of system schedulers and system optimizers, thus resulting in this condition having no impact at all; meaning that even if some of the assumptions used above are modified, they still will not result in detectible interference to the end user devices within the building.

Conclusion

It has been shown that on a wideband consumer booster it is possible for intermodulation distortion from uplink cellular signals to produce IMD products in the downlink path. However, for this to occur there has to be a very specific and very rare sequence of events. Even if these events do occur, it is very unlikely to impact the performance of the devices within the building, and even if it could occur, the system manages the channels and optimizes the spectrum for all devices on the system such that the devices can be switched to a different channel so there would be no impact to the performance of devices within the building.

[1] There are many references to the ITU indoor propagation model found online. Refer to the following link: https://en.wikipedia.org/wiki/ITU_model_for_indoor_attenuation. There's also the Indoor propagation loss formula from TIA, **TSB-84A**, which yields the same results as the ITU model.

[2] To calculate the probability of 3 mobile devices to all be on PCS, the formula is as follows:

$(12 / 30)^3 = 1728 / 27000 = 0.064 = 6.4\%$

[3] The formula to calculate the probability of two mobile devices being on one of the IMD frequencies is:

$(22.6\%)^2 = 5.1\%$, since 22.6% is the probability of being on a frequency that can cause an IMD condition.